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L. D. BATCHELOR, E. R. PARKER, and ROBERT McBRIDE

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STUDIES PRELIMINARY TO THE ESTABLISHMENT OF A SERIES OF FERTILIZER TRIALS IN A BEARING CITRUS GROVE[1]

L. D. BATCHELOR,[2] E. R. PARKER,[3] AND ROBERT McBRIDE[4]

INTRODUCTION

Many fertilizer and cultural trials which have been reported upon have been conducted under the implied assumption that the land on which the trials were located was 'uniform.' However, it has been evident to students of soil fertility during the last two decades, that, in reality, the productivity of the soil varies greatly in different sections of an experimental field. In some instances this variability of the soil has masked the effect of fertilizer trials to such a degree that the observed results have been very misleading.

Fertilizer trials conducted on land which has not been subject to previous study regarding its relative productivity *for the crop to be experimented with* must ordinarily be considered subject to large experimental errors. It is not sufficient to test the variability of land with one crop and then experiment with another. This point has been clearly demonstrated with many crops. It is now apparent with oranges on the Rubidoux experimental plots of the Citrus Experiment Station. Here such soil variations have been created by twenty years of differential fertilizer trials that there are very radical differences in the growth and production of orange and lemon trees on the several plots. Clover cover crops, however, have grown almost equally well on land which has not been fertilized for twenty years, and on plots which have received liberal applications of 'complete' fertilizer for the same period of time.

The present study, preliminary to the establishment of a rather large-scale fertilizer trial in a bearing orange grove, is the natural

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[1] Paper No. 178, University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, California.

[2] Professor of Orchard Management in the Citrus Experiment Station and Graduate School of Tropical Agriculture, and Horticulturist in the Experiment Station.

[3] Assistant in Orchard Management, Citrus Experiment Station.

[4] Assistant Superintendent of Cultivations, Citrus Experiment Station; died February 1, 1927.

outgrowth of the attempt to profit by the advances which have been made during the past two decades in the methods of conducting field trials. Such advances have resulted from the studies of many investigators both in this country and abroad. These have been freely drawn upon as a guide in these studies. The paper here presented is principally a general progress report in the nature of a popular discussion. A more strictly statistical analysis of the data well be prepared for publication in the near future.

The use of fertilizer material is practically a universal necessity of citrus culture in all parts of the world, and particularly in California. The per-acre charge for fertilizer materials in this state will vary from a few dollars to, in some cases, more than one hundred dollars a year. Any study which will give additional knowledge regarding the most effective and economical use of fertilizers, and provide a means by which the effects of various materials upon the soil may be studied, is of paramount interest to those engaged in the culture of citrus fruit in California.

Many difficulties are encountered in obtaining a satisfactory orchard to be used for a complex field trial. Commercial orchards are usually much too variable to use for experimental purposes. They are usually located upon land of uncertain history. They may be growing on land a portion of which has receiver a fertilizer treatment in the past which will create a difference in productivity of the soil, persistent over many years. The trees themselves may be subject to great inherent variability of size, vigor, and productivity. It has been demonstrated by several investigators that the rootstock has a great effect on the growth of the trees, at least during their early history. Because of these conditions a commercial grove may be entirely unsuited to experimental use. Other observations indicate that variations in certain characters of the top may be avoided by careful selection of bud wood. The general planting plan, also, of an experimental orchard may vary from that ordinarily employed in a commercial planting. Careful planning of an experimental planting may decrease the effort required in maintaining it, as compared with a commercial orchard adapted to the purpose. It also may facilitate the reduction of the experimental error by making possible the application of recognized methods of plot-trial technic.

The final value of the use of different fertilizer materials may not be fully established until they have been applied to the same plots for many years. The trials herein discussed may therefore be expected to continue for a period of twenty or thirty years. In consideration of

all of these facts it is desirable to carry on such trials upon publicly owned property. In this case change in ownership will not necessitate the modification or discontinuation of experiments which may, if continued, be productive of additional useful information.

In view of the foregoing comments it appeared necessary in 1914 that an orchard be established for the specific purpose of using it for fertilizer trials. The orchard described herein was planned in an effort to make it as satisfactory as possible for this use.

HISTORY OF LAND AND ESTABLISHMENT OF THE GROVE, INCLUDING PROPAGATION AND CULTURE

GENERAL HISTORY AND DESCRIPTION OF THE LAND

The establishment of the fertilizer trials herein discussed was one of the recognized objectives of the Citrus Experiment Station when a new site was purchased in the year 1914. The land chosen for planting the experimental grove was selected largely because of the apparent uniformity of the soil, and of the past cultural practices. Thus it was deemed particularly suitable for the purpose of conducting the trials under consideration. It seems desirable at this time to discuss somewhat in detail the history and the cultural treatment of the land during the periods preceding and following the planting of the trees, and especially during the latter period.

The soil is classified as Ramona loam by the United States Department of Agriculture soil survey.[5]

The land was first cleared in 1875 and planted to grain in 1876. From this date until the purchase of the land by the state in 1914 it was sown annually to barley or wheat, with the exception of an occasional year during which the soil was left fallow.

The land slopes gradually toward the west, with an average grade of 1½ per cent. No systematic effort to grade or level the land was made during the time it was cropped to grain, so far as is known. The ordinary plowing and harrowing, however, would fill in the small depressions which normally occur in newly cleared land, and doubtless the land presented a much smoother general aspect at the time of

[5] The soil is of old alluvial origin. It is derived from granite rock, and contains some mica. The soil to a depth of about 12 inches consists of a rather friable, light-textured, gritty loam of brown color. It is very slightly reddish brown when wet. The substratum is a compact gritty loam of greatly varying thickness; occasionally it extends to a depth of only 4 feet from the surface, but rarely extends to 20 feet from the surface. Below this formation the lower strata become gradually so compact that they can be penetrated only with great difficulty.

purchase in 1914, after thirty-eight years of dry farming, than it did when the brush was first cleared from the land in 1875. This natural filling in of depressions and the lowering of the higher local areas of soil, which would unavoidably occur during nearly four decades of farming, may in a measure account for some of the marked differences in productivity between small adjacent areas, which will be more fully discussed later.

The surface was sufficiently smooth in 1914 so that only a very slight amount of grading of the surface soil was necessary in preparing the land for irrigation. This grading was done only on the west edge of the field. The irrigation system was installed during the spring of 1917 and the land was irrigated for the first time during May and June of that year.

Figure 1 shows the shape of the field and the arrangement of the experimental plots.

THE PROPAGATION OF THE TREES

Selection in the Nursery.—It was recognized in planning the experiment that one of the requisites for the accuracy of the future experiments was to secure uncommonly uniform nursery trees. This is essential in order that the trees in all future plots will be as nearly equal as possible in size and yielding capacity. Extra care, beyond that used in the ordinary commercial production of trees, has been exercised to effect a reduction of differences between trees. Variations which might be inherent either in the rootstocks used or in the parent trees from which buds were taken have both been considered in the nursery.

The following measures were followed to produced especially uniform trees:

1. The sweet orange (*Citrus sinensis*) nursery stock which was transplanted from the seed bed to the nursery in 1914, was thoroughly culled and the undersized trees were discarded. These discards amounted to possibly 15 per cent of the seedlings.

2. After one year's growth in the nursery, and at the time the trees were budded in 1915, another selection of the small-sized trees was made, and these were discarded.

3. When the trees were dug from the nursery for transplanting to the grove in 1917, the small-sized budded trees were culled from the lot, making a third discarding of trees which lacked vigor and size. Thus from the establishment of the nursery until the actual planting of the grove, an endeavor was continuously made to produce a vigorous and unusually uniform lot of trees.

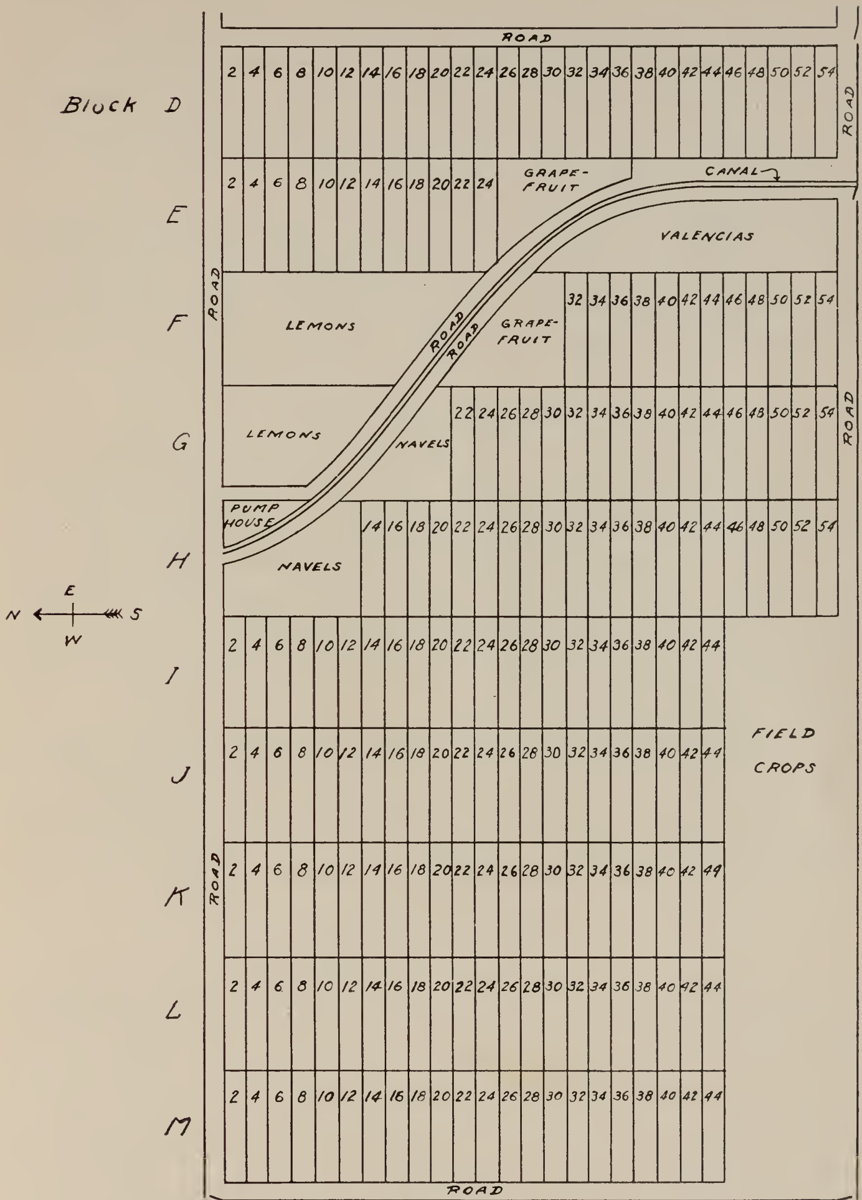

Fig. 1.—Plan of experimental field, showing arrangement of blocks and plots.

Selection of Buds—Plump, well-formed buds from mature bud wood were used for propagation purposes. Only such twigs were used as showed blossoms formed or in process of formation on the tips of the current season's growth at the time the bud wood was cut. The Washington Navel orange trees that are to form the experimental rows were propagated from trees for which yield records had been kept for several years. Only the heavy-producing trees were used as a source of bud wood.

The grapefruit trees were propagated from high-yielding parent trees of recorded performance. The Valencia bud wood, on the other hand, came from trees which were true to type, but not from performance-record trees.

PREPARING THE LAND

The actual preparation of the land for tree planting began during the fall and early winter of 1915. The land was deeply plowed at that time; part of the area was dry-plowed with a disk plow in the fall and the remainder was plowed with a moldboard plow after the rainy season began. The main portion of the field, that west of the canal lay in a rough fallow condition until the summer of 1916, when it was again plowed. This latter plowing was not deep and was done primarily to kill the weed growth.

The small portion of the field east of the canal (12.7 acres), as shown by figure 1, was not prepared exactly as heretofore noted for the main portion of the field. A crop of oat hay was produced on this area during the spring of 1916. The land was then left in grain stubble until tree planting began in the spring of 1917.

PLANTING THE TREES

During the spring of 1917, a narrow strip of land was plowed where each future tree row was to be located. The tree holes, 24 inches deep and 24 inches in diameter, were dug early in May. A preliminary soil survey was made by making a hole 4 feet deep from the surface of the ground with a soil tube, in each hole which was dug for tree planting. Slightly less than 10 per cent of the holes, that showed a semi-impervious layer within 4 feet of the surface of the ground were blasted. Before the actual planting began, the surface soil was filled back into the holes to a depth of 12 inches from the surface. The soil was then settled by irrigating the rows of holes before planting the trees. After the trees were planted, they were thoroughly irrigated to settle the soil around the roots.

The entire orchard was planted in pairs of blocks each ten trees deep. Separate irrigation lines were ultimately laid for each of these blocks, so that each block of trees may be irrigated separately. The Washington Navel orange trees were planted as the test variety. Each alternate row constitutes an experimental plot and contains eight trees of this variety. The first tree of each test row, next to the pipe

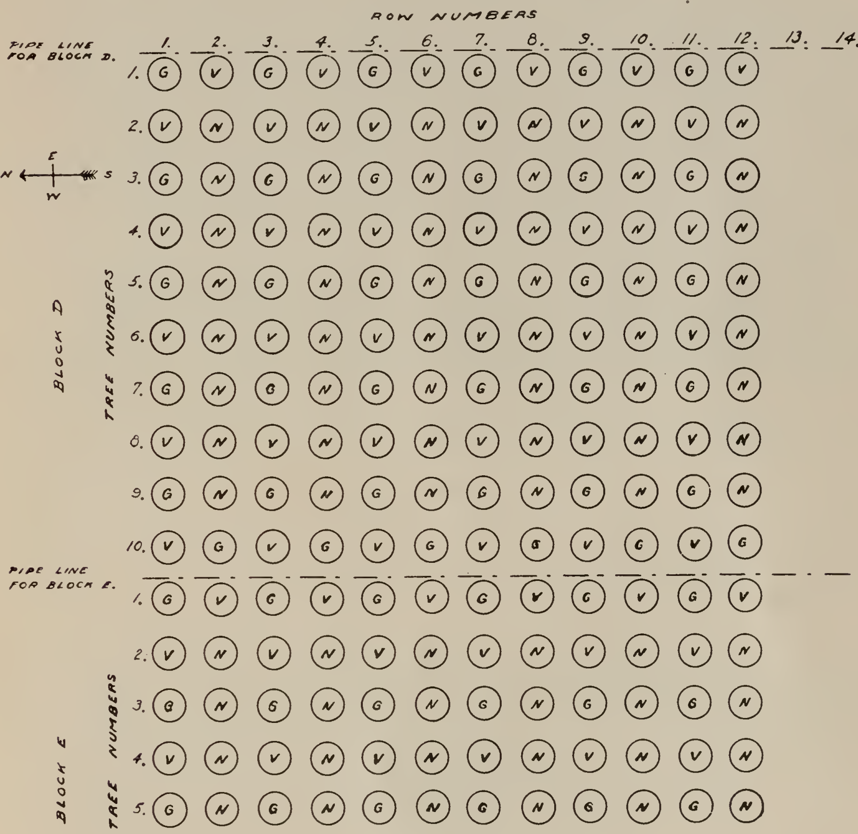

Fig. 2.—Showing arrangement of trees in plots and guard rows.

line, however, is a Valencia orange tree and the tenth tree is a grapefruit tree. The rows alternating with the test rows are planted throughout the orchard to Valencia and grapefruit trees alternating. These latter rows will be considered guard rows between the fertilizer plots and are designed to prevent to some extent the overlapping of the effects of different fertilizer treatments from one Navel row to another. The plan of planting may be more clearly understood by reference to figure 2, which shows portions of two blocks of the experimental field.

INTERCROPPING THE GROVE DURING THE SUMMER SEASONS OF THE FIRST FOUR YEARS

The land between the tree rows remained in a fallow condition during the planting operations. As soon as the trees were set, this space was prepared for planting beans. The beans were planted in rows 36 inches apart with six rows of beans in each interspace between the orange tree rows.

During the first four years of the existence of the grove it was inter-cropped each summer to Blackeye beans (*Vigna sinensis*) and planted to a bitter clover (*Melilotus indica*) cover crop each fall. The winter cover crop was planted in September and plowed under during the following February or March. Figure 3 shows a view of a portion of the experimental field during the first year, before the harvest of the bean crop.

The yearly intercropping of the land to Blackeye beans for four years furnished considerable straw to apply as a fertilizer material to the young trees. This bean straw was applied in deep furrows. The first year a furrow was made with a large moldboard plow on each side of the tree rows at a distance of 2½ feet from the trees. The bean straw was buried in the furrows on two sides of the trees, distributed along a space of 3 or 4 feet in the furrow. An average of 20 pounds of bean straw per tree was applied.

During the fall of the second year (1918) all the bean straw produced as an inter-crop and also about ten tons produced on nearby fields, was applied in furrows to the 48 acres of the experimental field. The furrows were made parallel to the tree rows, placed about one foot further away from the trees than the furrows of the 1917 season. In addition to this, one furrow on each side of the trees was made across the tree rows, at a distance of 4 feet from the tree trunk. All the furrows were made about 12 inches deep. The straw was applied at the rate of 24 pounds per tree. Figure 4 shows the method of applying the straw along the tree rows during the second year. It was trampeled down, and then covered over by using a moldboard plow. An examination of this straw in January, 1919, showed that the straw was covered with an average of 5 inches of soil.

During the early fall of 1919 furrows were again made parallel to the tree rows one foot further away from the rows than the previous year, making a total of 4½ feet and straw was applied at the rate of 17 pounds per tree.

Fig. 3.—View of part of the experimental orchard, looking in southwestern direction, during the first year (1917). The summer inter-crop between the tree rows may be seen.

Fig. 4.—Method of applying bean straw in furrows during second year (1918).

The orchard was intercropped to Blackeye beans during the summer of 1920 for the last time. After the bean harvest of that year the straw was applied in furrows made across the tree rows and so placed that they were about one foot from the cross furrows made in 1918 and thus approximately 5 feet from the tree trunks. Ten pounds of straw was applied per tree; only 75 per cent of this straw had been produced as an intercrop, the remainder having been grown on nearby land.

Fig. 5.—Summer cover crop of Whippoorwill cowpeas, 1921.

CULTURE OF THE GROVE DURING SUMMER SEASONS OF FIFTH TO NINTH YEARS, INCLUSIVE

In both 1921 and 1922, summer cover crops of Whippoorwill cowpeas (*Vigna sinensis*) were grown. The cowpeas were planted in rows and cultivated during the interval between irrigations until the growth of their tops made this operation no longer practicable. They were planted in May and disked under about the middle of August with a double disk and tractor power. A relatively heavy production was secured each year. The green weight of the crop for 1921 was 10.5 tons to a solid acre of cowpeas, and for 1922 it was 13.8 tons. Although the cowpeas were planted in the tree rows in 1921, the irrigation water did not reach them well and the crop there was stunted.

For this reason only three-quarters of the land was really productive of a cover crop that year. During the 1922 season, however, permanent irrigation furrows were made in the form of a figure eight between each two trees in the tree rows. This method of irrigation produced as good tonnage of cowpeas in the tree rows as in the interspaces, and all the land except that actually under the trees produced a summer cover crop. The appearance of the grove and the summer cover crop in 1921 is well illustrated by figure 5.

WINTER COVER-CROPPING

Throughout the entire history of the grove with the exception of 1926–27, a cover crop has been grown during the winter seasons. Yellow bitter clover (*M. indica*) has been used every year except 1923–24 when purple vetch (*V. atropurpurea*) was used. A good commercial tonnage of winter cover crop has been grown six years out of nine. During the spring of 1922 and also of 1923 the tonnage plowed under was very light, owing to the destruction during the previous fall months of many of the young clover plants by the alfalfa caterpillar (*Eurymus eurytheme*). The crop of purple vetch plowed under in 1924 was also relatively light because of the ravages of the destructive pea aphis (*Macrosiphum pisi*), which greatly reduced the growth of the crop the last two weeks before it was plowed under. The average annual yield was about 11 tons of green weight to a solid acre of cover crop. The approximate average green weight per acre was 13 tons in 1925 and 11 tons in 1926.

During the years when Blackeye beans were grown as an intercrop, the winter cover crop was sown as early as possible after the bean harvest, which was usually the latter part of September or early October. It was then plowed under by the middle of March. This gave plenty of time for the green material to decompose and the land to be prepared for bean planting. Since the fall of 1921 the winter cover crop has been planted earlier than heretofore, usually about the last week in August or the first week in September. The crops have been plowed under during the last ten days in February for the last five years. Throughout the whole life of the grove the winter cover crop has been plowed under to a depth of from 9 to 10 inches with a moldboard plow and tractor power.

During the summer seasons of 1923 to 1926, inclusive, clean culture was practiced. The first two years of this period the soil was worked two or three times during the time intervening between two irrigations. The usual practice was to harrow over the grove with a

spike-tooth harrow as soon as the land was sufficiently dried out after an irrigation. It was then cultivated both with the tree rows and crosswise, with a heavy cultivator drawn by a tractor. This program of cultivation for the summer months was judged to be excessive, and was modified beginning with the summer of 1925. During the last three summers the irrigation furrows have been allowed to become thoroughly dry without being 'pulled in' by the use of a harrow. The land has been merely cultivated, ordinarily only one way, with a heavy cultivator, between irrigations. The land has been thoroughly dry, so that some clods have been formed by the cultivation. The furrows for the next irrigation have been made approximately one week after cultivation and have been allowed to remain open for a week or ten days before irrigation. The modification of the cultural practice by reducing the number of cultivations between irrigations has been followed by a marked improvement in the readiness with which the soil has absorbed irrigation water.

IRRIGATION PRACTICE

The irrigation practice followed has been in general similar to that employed under commercial management of like properties of the district. The nature of the soil and the slope of the land has made it advisable to use the furrow method of irrigation exclusively. From 2½ to 4 acre inches of water per acre has been the usual single application. During the years when intercrops or summer cover-crops were grown between the tree rows the land was irrigated in accordance with the demands of the annual crop, with the exception that one furrow on each side of the young trees was used to give them water at frequent intervals, regardless of the needs of the intercrop.

The time of irrigation of the grove and cover crops has always been determined by the moisture content of the soil. This has ordinarily been accomplished by the frequent use of a soil tube in various parts of the field. In addition, beginning with the year 1922, a record has been kept of the moisture content of the soil, in plots distributed at random throughout the field. When only the needs of the trees have been considered the average interval between irrigations during the summer months has been from twenty-five to thirty days.

The winter cover crops have been irrigated at frequent intervals during the fall months. The usual absence of rains during the period from September to November, inclusive, has made it advisable during most years to apply a light irrigation every fourteen to twenty-one

days in order to keep up a continuous growth of the young cover-crop plants. The total amount of water applied annually has varied from 30 to 48 acre inches per acre, according to the rainfall and the needs of the intercrops.

One notable objection to the growing of a summer cover crop of cowpeas has been the lack of penetration of the irrigation water, when it is necessary to run water time after time in the same irrigation furrows. During the latter part of the growth of the cover crop,

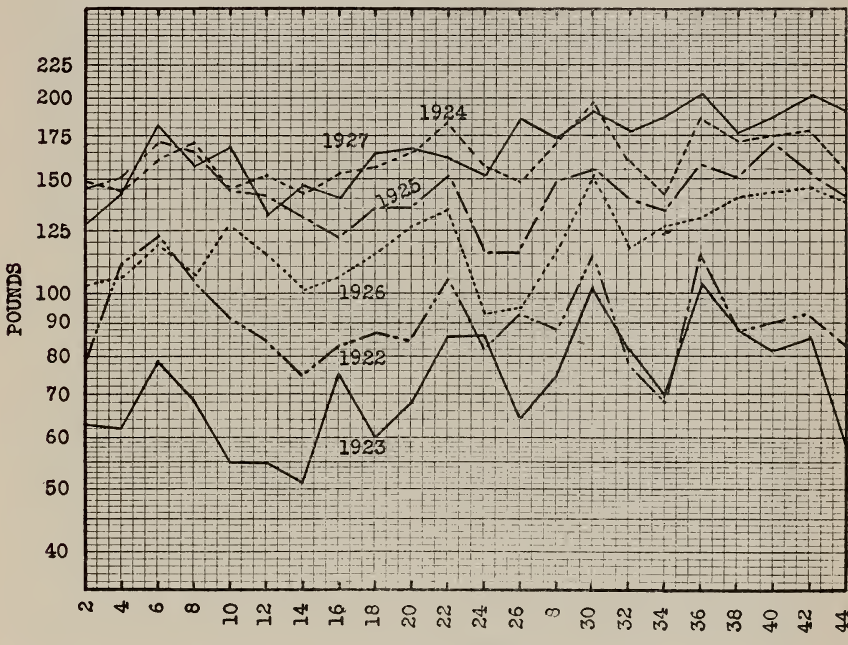

Fig. 6.—Average yield per tree in each plot of Block I, for each of six years, 1922 to 1927, inclusive.

from July 15 to August 15, it has been practically impossible to wet the soil below 2 feet from the surface. This system of culture may be seriously objected to on the Ramona loam soil, and similar soil types, because of the lack of penetration of the irrigation water. The maximum demand of the intercrop for water comes at a time when the midsummer demand of the fruit-laden trees is also high. It has been literally impossible to apply sufficient water for both crops on the soil types here encountered. Allowing the water to run 24 hours per irrigation it was impossible to apply more than 0.8 to 1.0 acre inch per acre. With a 48-hour run usually less than 2.0 acre

inches per acre could be applied. Running water continuously for 48 to 72 hours did not accomplish a satisfactory irrigation. Under such conditions it has been necessary to apply water every seven to ten days and even then the very small amount taken up by the soil was insufficient for the best development of the young trees.

The results of the two years of summer cropping to Whippoorwill cowpeas in this orchard have shown clearly that practically no summer growth of the trees took place from June to August, inclusive.

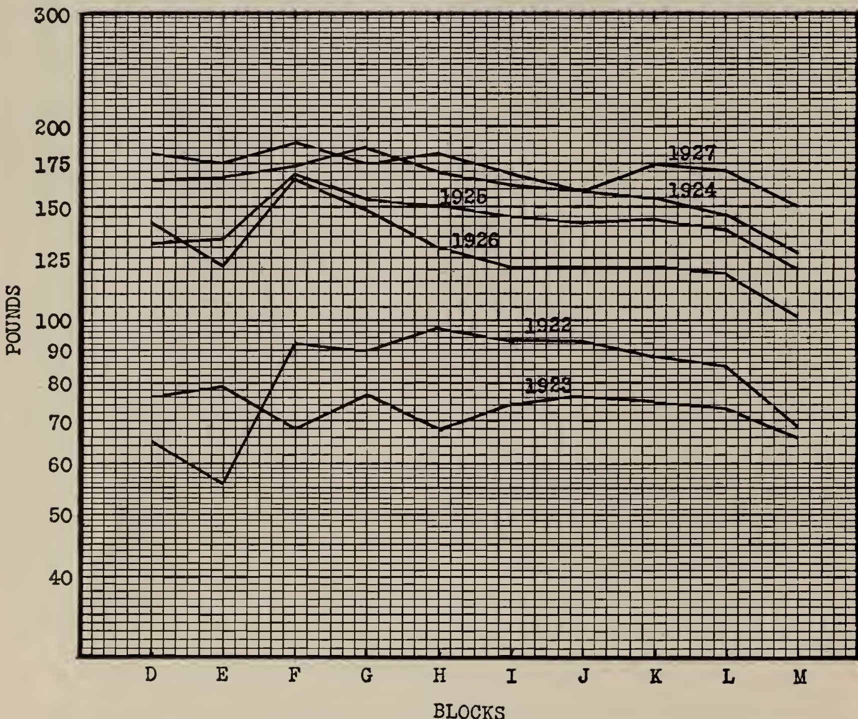

Fig. 7.—Average yield per tree in each block, for each of six years, 1922 to 1927, inclusive.

A month after the cover crop was disked under, or about September 15, growth started on the trees and became exceedingly great by October 15 to November 1. The frost hazard naturally became much greater under such conditions than when the trees made three or four normal cycles of growth during the growing season and entered the autumn period in a well-matured condition.

The practices which have been pursued in the development and culture of this orchard have resulted in the production of a very satisfactory property from a commercial viewpoint. The size and

productivity which the trees have attained, especially during the first six-year period, have been somewhat greater than that usually reached during the same interval of time on similar properties.

TABLE 1

AVERAGE YIELD PER TREE IN EACH PLOT OF BLOCK I, FOR EACH OF SIX YEARS, 1922 TO 1927, INCLUSIVE

Year	Plot																					
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
	Average yield per tree, in pounds																					
1922	90	112	123	104	91	85	75	83	87	85	105	82	93	88	114	78	68	117	87	90	93	83
1923	63	62	79	68	55	55	51	75	60	68	86	86	64	75	103	81	69	104	88	82	86	58
1924	149	145	162	171	146	151	143	153	156	165	183	158	147	172	196	162	142	186	172	175	177	153
1925	145	151	171	164	145	141	131	123	135	135	153	116	116	149	155	140	134	158	152	171	157	140
1926	103	106	119	107	126	113	101	106	116	127	136	93	95	117	151	117	128	132	141	144	146	139
1927	128	144	183	157	168	132	146	140	164	167	163	154	186	172	193	178	187	203	177	187	204	181
Avg.	113	120	140	129	122	113	108	113	120	125	138	115	117	129	152	126	121	150	136	142	144	126

It is believed that the practice of growing leguminous intercrops has been of distinct advantage in improving and maintaining the yields of this orchard. The appearance of the trees and the yields now indicate, however, that the growing of winter cover crops as practiced and without the use of fertilizer material is not maintaining the trees in a condition of greatest vigor. As indicated in figures 6 and 7 and also in table 1, the yields of the trees have not been increased since 1924 until the year 1927. Although the latter was an exceptionally good year for orange production in this district, only a slight increase over the yield of 1924 was recorded. The present appearance of the trees also shows that they are not in a condition of luxuriant growth. In comparison with well-fertilized orchards in the vicinity, the new growth appearing on the Navel orange trees during the 1925–1926 season in this orchard was slight and small-leaved. This is illustrated by figure 8, which shows a tree of the average size and production for the entire field, photographed in 1927. At the end of the ten-year period it is believed that some nutrient materials are present in the soil in such low concentrations that they are beginning to limit the growth and productivity of the trees. This condition makes the present, therefore, an ideal time to commence the differential treatments, since a relatively early response to beneficial treatments may be anticipated.

OBSERVATIONS REGARDING THE VARIATION IN THE SIZE AND PRODUCTIVITY OF THE TREES

TRUNK MEASUREMENTS

Records have been made annually of the growth of the trees. Trunk-circumference measurements have been made during the whole period since the trees were planted. The yearly trunk measurements have been at the same position on the trunk. Each tree has been marked with a painted band showing the place of measurement. The smallest circumference on the trunk between the swell of the branches and the swell of the root system was chosen for this measurement. This measurement was converted into area of cross section. Space will not permit presenting all the data which show the amount of variation among all the individual trees for each year. However, an illustration of the amount of variation in the plots is shown by table 2, which presents the average trunk size per tree, in each plot, in 1926.

TABLE 2

AVERAGE TRUNK MEASUREMENT PER TREE IN EACH PLOT FOR 1926

Plot	Block									
	M	L	K	J	I	H	G	F	E	D
	Area of cross section in square centimeters									
2	111	109	104	117	129				132	134
4	111	114	112	105	129				134	142
6	118	114	113	107	128				121	127
8	119	113	109	129	133				130	139
10	115	120	127	123	141				135	136
12	113	125	122	117	130				135	129
14	126	121	137	120	146	153			132	128
16	122	122	131	120	135	148			103	114
18	122	117	120	127	149	136			133	131
20	115	115	126	127	143	142			128	126
22	129	122	133	127	134	140	140		129	127
24	132	*	127	124	129	137	133		118	125
26	124	126	117	131	137	128	129			128
28	127	122	141	127	123	127	134			128
30	128	121	133	139	132	127	130			137
32	120	119	128	126	138	122	129	144		132
34	114	*	135	119	139	132	135	124		125
36	122	119	133	123	133	136	137	132		126
38	107	117	114	123	122	128	136	122		125
40	128	118	134	124	118	123	126	123		130
42	118	110	120	118	136	123	131	132		128
44	112	121	132	130	113	115	127	131		133
46						118	134	147		139
48						127	132	125		126
50						131	128	128		137
52						129	134	143		138
54						135	142	*		131

* Plots omitted because of injury to trees.

In averaging the eight trees of a plot, the variation in the individual trees has naturally been leveled to some extent. On the basis of the mean size of the trees in each plot, the differences are greater than would be expected, when the care spent in establishing a uniform grove is taken into consideration.

Fig. 8.—Individual Navel orange tree of average size and production at time of starting the fertilizer trials, 1927. (Tree E-4-3.)

The trees in plot E–16 are among the smallest in trunk cross-section; those in plot H–14 are 49 per cent larger. The measurements of the trees in these plots in 1918, one year after the trees were planted in the orchard, showed that plot H–14 was even then 31 per cent larger than plot E–16.

Apparently the chance distribution of the trees at the time the orchard was planted accounts in a large degree for subnormal-sized trees being originally grouped together in plot E–16. In addition to this, the fact that this plot has been making slower growth than

some of the other plots leads us to conclude that E–16 is also located on soil which is subnormal in productivity in comparison with many other plots of the field.

It seems probable that the present range in plot averages of tree size could have been materially reduced by so distributing the different-sized trees at the time of planting as to make the plot averages uniform throughout the field. The distribution of the trees by pure chance might be expected to locate a group of either exceptionally large or exceptionally small trees in the same plot occasionally.

VOLUME OF TOPS

Top-volume measurements have been made yearly since 1921, and have been recorded in cubic feet. The measurements over and around the trees have been taken to the nearest foot by means of a fumigation tent, and the cubic contents calculated by the conventional method used in determining fumigation dosage.

TABLE 3

AVERAGE TOP VOLUME PER TREE IN EACH PLOT, 1926

Plot	Block									
	M	L	K	J	I	H	G	F	E	D
	Average top volume per tree, in cubic feet									
2	733	758	757	780	927				874	868
4	725	769	868	703	858				954	921
6	845	761	815	723	947				761	829
8	776	750	784	817	934				909	1014
10	755	777	800	869	1014				936	936
12	735	825	818	801	926				848	814
14	853	887	876	791	921	1115			881	783
16	812	831	888	804	855	992			596	710
18	787	827	825	803	921	917			860	895
20	699	821	935	893	945	1001			836	811
22	803	765	891	969	995	983	901		802	871
24	764	*	857	944	858	1005	898		761	799
26	759	799	778	819	857	979	829			889
28	862	823	863	840	863	965	973			839
30	756	754	847	887	854	930	866			877
32	799	791	799	904	845	797	918	1071		784
34	738	*	845	780	942	866	919	916		732
36	750	790	843	848	947	901	975	976		813
38	727	801	817	771	806	807	927	747		809
40	791	819	826	867	848	878	854	865		830
42	696	730	885	822	894	882	789	905		811
44	710	813	832	850	796	851	873	896		849
46						815	885	963		944
48						843	849	901		750
50						840	840	895		924
52						829	920	1006		847
54						855	959	*		823

* Plots omitted because of injury to trees.

The extent of the variation in top volume between the several plots is shown by table 3. This presents the average top volume per tree, in each plot, for the entire grove in 1926. The greatest range in variability is shown in comparing plot H–14 with E–16; the former, with an average top volume of 1,115 cubic feet, is 87 per cent larger than the latter plot, with only 596 cubic feet as an average top volume. The differences in top volume are somewhat larger than the

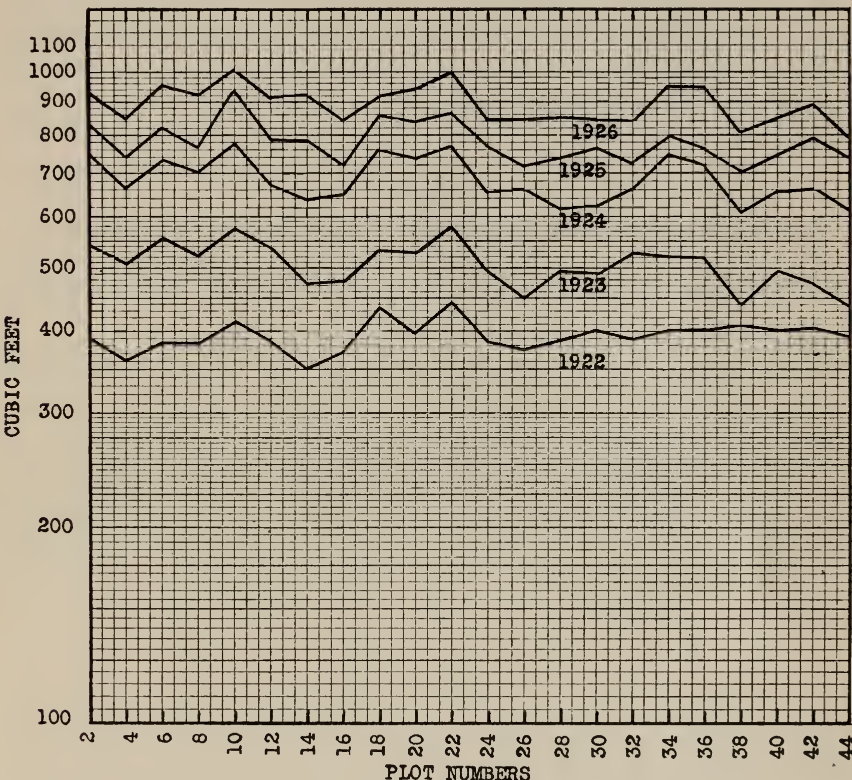

Fig. 9.—Average top volume per tree in each plot of Block I, 1922–1926, inclusive.

extreme range in variation in size as indicated by trunk measurement. There is, however, a close correlation between top volume and trunk measurement.

It has been notable that the differences in size between the several plots during the past four years have been very consistent year after year. The plots which included trees of small size in 1921 as a rule still have relatively small trees in 1926. This is brought out by table 4, which shows changes in the top volume of the trees for block I for five years. The data are shown graphically in figure 9.

The linear plotting of the cubical measurements of the top volume has exaggerated the apparent differences in the volume sizes of the plots as judged by visual observation in the field. The graphs are presented primarily to show the parallel trend of the growth of the plots from year to year and the tendency for the large plots to remain relatively large while the small plots remain consistently small. Further reference to this subject is also made under the heading of abnormal trees (see p. 28). This tendency has some exceptions, as is shown by plot 28, block I, compared with plot 26, block I, during 1924 and in the other four years. Such exceptions in the trend of growth occur in only a small minority of cases.

TABLE 4

Average Top Volume Per Tree in each Plot of Block I, for each Year, 1922–1926, Inclusive

Year	Plot																					
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
	Average top volume per tree, in cubic feet																					
1922	390	365	385	387	413	391	357	375	437	398	443	391	379	389	407	393	403	407	413	405	409	399
1923	540	518	561	533	577	548	479	482	534	534	586	496	460	497	492	530	525	528	445	497	480	448
1924	756	667	734	702	793	673	643	655	760	743	775	649	671	634	628	663	747	729	615	663	673	629
1925	828	754	826	775	928	793	791	726	874	847	868	786	728	742	773	739	791	772	713	751	788	754
1926	927	858	947	934	1014	926	921	855	920	945	995	858	857	863	854	845	942	947	806	848	894	796

PRODUCTION

The success or failure of the future fertilizer treatments will be finally judged by their effect upon fruit production. The yield records, before any differential treatments were started, therefore become of greatest interest in interpreting the future observations. The average annual production per tree in each plot for a six-year period is shown in table 5. As a general rule the largest Navel orange trees have also been the most productive, although there are notable exceptions to this prevailing tendency. The degree of variation in the yields of the plots has, however, been even greater than the variation in the size of the trees. The striking variation in the plot yields is in harmony with other studies which have been conducted for the purpose of determining the accuracy of plot trials.[6] There is a difference

[6] Batchelor, L. D., and H. S. Reed. The relation of the variability of yields of fruit trees to the accuracy of field trials. Jour. Agr. Res. 12:245–283. 1918.

of practically 109 per cent between the lowest yielding plot, M–8, which produced an annual average of 79 pounds of oranges per tree for the entire six-year period, and plot F–44, which produced 165 pounds per tree annually during the same period. The two plots showing the extremes of productivity are located one-third of a mile apart. Such a variation in productivity is not strange in comparing areas of soil located at such a distance from each other, even though they are a part of a block of land which has been treated as uniformly as is practicable. A comparison of adjacent plots, however, shows varaitions in production in some cases of 30 to 40 per cent. This is illustrated by referring to table 5 and comparing the yields of the following pairs of adjacent plots: E–16 and E–14; G–26 and G–28; J–6 and I–6; and M–22 and L–22.

TABLE 5

AVERAGE ANNUAL YIELD PER TREE IN EACH PLOT FOR THE SIX-YEAR PERIOD, 1922 TO 1927, INCLUSIVE

Plot	Block									
	M	L	K	J	I	H	G	F	E	D
	Average annual yield per tree, in pounds									
2	87	103	96	103	113				100	121
4	95	106	110	104	120				127	140
6	111	110	109	99	140				116	141
8	79	112	99	115	129				139	137
10	98	113	116	110	122				130	128
12	102	109	122	128	113				140	133
14	93	126	137	128	108	132			133	138
16	100	116	129	119	113	130			100	107
18	93	115	112	119	120	132			124	105
20	98	116	127	135	125	131			116	105
22	98	138	132	137	138	116	120		122	124
24	103	*	121	119	115	114	123		118	121
26	97	121	104	110	117	115	103			130
28	119	119	129	132	129	138	141			116
30	108	131	148	130	152	153	140			136
32	127	127	135	134	126	129	133	152		139
34	119	*	140	134	121	139	135	128		128
36	135	147	146	147	150	143	127	138		136
38	120	137	119	124	136	142	148	129		133
40	121	138	135	139	142	150	133	131		122
42	114	128	157	146	144	142	155	153		138
44	107	126	143	135	126	140	144	165		144
46						126	155	155		146
48						129	150	140		117
50						134	142	131		115
52						114	150	149		122
54						114	136	*		108

* Plots omitted because of injury to trees.

The persistent tendency for high or low-yielding plots to remain in the same respective class is illustrated by figure 6 (page 15). This figure shows the average annual production per tree in each plot of block I during the six-year period. Plots which are high producers on year apparently tend to be high other years, while in general low-producing plots have been consistently low in yield. Plot 32, for example, has each year consistently produced less than plot 30, and plot 34 has consistently produced less than plot 36 during the same period.

TABLE 6

MEAN YEARLY YIELD PER TREE IN EACH BLOCK
(In pounds)

Block	1922	1923	1924	1925	1926	1927
D	64.8	76.0	165.0	133.0	141.9	181.0
E	56.3	78.7	166.2	134 0	122.2	174.5
F	91.9	68.1	173.8	168.3	166.2	187.5
G	89.1	77.1	179.7	154.4	148.4	174.8
H	96.6	68.1	170.3	151.2	129.1	183.0
I	92.5	73.5	162.0	144.6	121.0	169.0
J	93.2	75.7	156.9	142.4	121.5	158.8
K	87.9	75.3	155.1	142.6	121.4	174.5
L	85.2	73.1	146.1	139.2	116.6	171.3
M	68.5	66.0	126.6	120.4	101.4	150.0

The two groups of factors which are most persistently operative in causing the variation in production are: first, the inherent qualities of the tree due to character and vigor of rootstock and top; second, the variability of the productivity of the soil in one part of the field compared with another. In considering the yields on the basis of the average production per plot of eight trees each, the extremes of variability among individual trees are largely compensated for. The leveling effect of averaging the yields of the eight trees in each plot over a six-year period makes it possible for this average figure to be used as a fairly reliable index of the natural productivity of the soil on which the respective plots are located. Inasmuch as the individual trees were distributed purely by chance over the entire field, it seems reasonable to believe that the consistency for high and low production among plots as illustrated by block I, is due primarily to variations in the productivity of the soil.

This interpretation of the relative importance of the two groups of factors causing the variation in the average production of plots is further substantiated by considering the average production of the several blocks as units, over the six-year period. These data are pre-

sented in table 6, which shows a relatively consistent tendency for different blocks in the field to be high or low producers. In this case each block is represented by the average yield of eleven or more plots; thus the variability of 88 or more trees is leveled by their average, which indicates the production of each respective block.

Figure 7 shows the same data graphically. From this it is clearly seen that the relative productivity of the respective blocks is not absolutely consistent from year to year, but there is nevertheless a marked tendency for the highest-yielding blocks, such as F and G, to remain so throughout the period, and the lowest-yielding, block M, to continue as such.

In allocating the ultimate unit plots for each respective fertilizer treatment, an attempt has been made to use differences in the productive capacity of different portions of the field as one factor in reaching a decision on this subject. With a previous knowledge of the magnitude of relative differences between all plots, the four repetitions of a given treatment may be so arranged that each treatment may be tried on plots the summation yield of which, prior to the start of the experiments, is approximately equal to that of the summation yield of the plots of other treatments. By this method all treatments may be tried on an equal footing, without being handicapped or favored by being located on plots the summation yield of which is excessively low or high. This procedure may materially reduce the experimental error inherent in the trials, provided the differences which are apparent at the beginning of the fertilizer trials prove to be consistent to some degree. Provision has been made to study the degree of consistency exhibited in the future, in comparison with the first six-year period. This aspect of the problem will be discussed in a following section.

ATTEMPTS TO DETERMINE CAUSES OF VARIATION

The underlying causes of the persistent variation in the production of individual trees and plots which must be considered normal for this orchard are probably very complex, and beyond a full explanation at this time. A more complete knowledge of the factors involved would be of inestimable value in planning an experiment such as that which is now being initiated. It would also be a great aid in the future interpretation of the effects of specific treatments.

Several attempts have been made to determine the fundamental causes of the varying performance of individual trees and of individual plots. Soil surveys have been conducted at two distinct periods

throughout the orchard. Borings were made to a depth of 4 feet in the tree holes at the time of planting. At a later date composite soil samples were taken in each plot to a depth of 6 feet. The moisture retentiveness of the soil in the root zone of the orange trees has been determined in a large section of the field, and has been studied in relation to the growth and yield of the trees in that area. The amount of moisture in the soil of certain representative plots has been determined over a considerable period of time. This has been studied with regard both to the absolute amount of moisture and to the amount theoretically available to the tree, as indicated by the wilting coefficient of the soil in those plots. The total amounts and the seasonal distribution of nitrates in the soil have also been studied in high and low-yielding plots. Individual trees have been inspected for differences in relative infestation of various parasites, particularly the citrus nematode, *Tylenchulus semipenetrans*. In addition, all of the trees in the plots showing the greatest extremes of production have been examined for abnormalities in the distribution of the main roots for a distance of about one foot from the trunk of the tree.

However, none of the factors enumerated appear to be the primary cause of the differences in the yield performances which have been observed. The varying behavior of individual normal trees, and especially of individual plots and larger areas under conditions of uniform culture, must be due to certain factors or combinations of factors which have not yet been brought to light, and apparently for want of a better explanatory term, may be described only in the most general way as the variability in the productivity of the soil. Continued study of this subject may be productive of more specific information.

VARIATION IN COMPARISON WITH THAT OF AVERAGE GROVES

In spite of the variations in the growth and production of the trees of this field which have been cited, it is believed that this planting is singularly uniform in comparison with the average citrus grove. This fact has been brought out in statistical studies of the variability of this and other orchards. In appearance the trees are strikingly similar. This relative uniformity is shown by figure 10, which represents a view of the grove taken in 1927 from the same point and looking in the same direction as was figure 3, taken in 1917. The appearance of the trees along the pipe line of block D in 1927, as shown by figure 11, also illustrates the uniformity of the trees. Figure 11 also shows the relation of the standpipes to the trees, and the marking of the individual treatment plots.

Fig. 10.—View of grove in 1927 showing relative uniformity of trees. This view taken from the same location as that shown in figure 3.

Fig. 11.—Appearance of trees along the pipe line of block D, in 1927, showing uniformity of growth.

ABNORMAL TREES

The trees in this orchard have passed through most of the ordinary vicissitudes of a commercial orchard. As might be expected at the end of the first ten-year period, there are certain trees which are clearly subnormal in their growth and production. The yields and the growth records of such trees have not been included in the average yields. When four or more trees in any one plot are known to be abnormal the records for the entire plot have been discarded.

TABLE 7

COMPARATIVE SIZES OF NORMAL AND SUBNORMAL TREES ONE YEAR AFTER PLANTING AND EIGHT YEARS LATER

Plot in which abnormal tree is located	Area of cross section of trunk			
	1918		1926	
	Subnormal tree *sq. cm.*	Average of two adjacent normal trees *sq. cm.*	Subnormal tree *sq. cm.*	Average of two adjacent normal trees in same plot *sq. cm.*
D-40	4.44	6.10	85.6	134.5
F-44	5.05	6.45	99.2	121.5
K-36	3.55	6.01	106.0	126.9
L- 6	3.04	7.94	77.5	120.3
L-16	3.23	6.41	108.4	120.5
L-18	4.08	5.91	100.9	112.8
L-22	3.23	6.31	74.0	129.7

The causes of most of the subnormal conditions of individual trees are clearly apparent. Such trees are most commonly isolated and have therefore not destroyed the usefulness of the remainder of the plot. The plots in such cases have been reduced to seven trees. In only three instances have whole plots been discarded; in these instances four or more of the trees in a single plot were injured to some degree by pocket gophers during the winter of 1919–20. At that time the grove was being given ordinary commercial culture and had not been assigned to any one for statistical study. The trees injured most severely were pulled out and young trees were planted in their places. Others, less severely injured by gophers, have been inarched with four seedlings per tree. Some of these have entirely recovered and may be considered normal trees at the present time. Others must clearly be maintained several years longer before their yield can be used in connection with the fertilizer trials.

Among the 1,592 Washington Navel trees which were planted as test trees, 7 trees are clearly subnormal for unknown reasons. It is possible that they are on inferior rootstocks, although this can not be proved at the present time. The selection of the trees which was made at the time the grove was planted was based upon the judgment of the foreman of operations. No actual measurements of the trees

Fig. 12.—Subnormal tree showing small size of tree in 1927 (Tree L-18-4).

were made, and no attempt was made to have the average size of the trees in each plot the same. From records taken in May 1918, it is clear that all of the trees which are subnormal at the present time were smaller than the average trees in the respective plots at the time the grove was planted. Table 7 gives the past and present sizes of subnormal trees compared with the average of the two adjacent normal trees in their respective plots. The small size of the subnormal trees is illustrated by the one shown in figure 12, which has been photographed on the same scale as the normal tree shown in figure 8.

It is plain from table 7 that the seven trees therein considered are subnormal in vigor and have been so from the time they were planted in the orchard. This is further emphasized by table 8, which compares the yield of the subnormal trees with the average yield of the two adjacent trees for each year, 1921 to 1927, inclusive.

TABLE 8

YIELD OF SUBNORMAL TREES AND AVERAGE YIELD OF TWO ADJACENT NORMAL TREES IN THE SAME PLOT FOR EACH OF SEVEN YEARS, 1921 TO 1927, INCLUSIVE
(In pounds)

Plot in which abnormal tree is located	1921		1922		1923		1924		1925		1926		1927	
	Sub-normal	Normal	Sub-normal	Normal	Sub-normal	Normal	Sub-normal	Normal	Sub-normal	Normal	Sub-normal	Normal	Sub-normal	Normal
D-40	0	2	13	36	2	75	51	187	41	139	68	116	*	138
F-44	4	32	13	119	14	87		184	29	187	24	195	13	207
K-36	4	16	132	64	39	72	49	168	28	173	78	142	128	187
L- 6	4	36	8	98	12	68	41	123	44	150	19	73	24	160
L-16	8	32	4	98	45	59	50	152	20	134	0	73	18	161
L-18	4	34	34	102	25	61	78	125	64	135	19	87	15	195
L-22	2	34	51	100	48	119	62	184	42	142	0	107	20	178

* Special treatment of tree interfered with accuracy of record

In the present condition of the subnormal trees, their yields cannot properly be used in computing the average yields for the respective plots to which they belong. If they do not respond to the inarching which has been performed on them and make a more nearly normal growth, they may soon be removed and the space replanted to young trees.

VARIATION IN THE YIELDS OF THE PLOTS IN RELATION TO PLANNING THE FUTURE FERTILIZER TRIALS

NUMBER OF TREES FOR EACH TREATMENT

With such great variation in the yields of the plots as is evident from table 5, it becomes a matter of important consideration to arrange the fertilizer trials of the future so that each treatment will have as nearly as practicable an opportunity to be fairly tested. Statistical studies made in other orange groves have indicated that it is desirable to have a minimum of thirty-two trees assigned to each fertilizer treatment. This grove was planned in such a way that this number might be used.

EFFECT OF GROUPING ALL LIKE-TREATED TREES TOGETHER

Many fertilizer experiments have been conducted during the past two decades in which comparisons were made between two differently treated plots, without including any repetitions of the treatments in several parts of the experimental field. In accordance with the laws of simple sampling, however, the division of a treatment among two or more ultimate unit plots located in different parts of the field may be expected to give greater accuracy in determining the value of a treatment than if the given treatment had been applied to the same number of ultimate unit plots located adjacent to each other. A study of the yield records of the field of Navel oranges discussed here will illustrate the principle involved.

TABLE 9

THE AVERAGE ANNUAL YIELDS PER TREE OF THE ULTIMATE UNIT PLOTS OF FORTY-NINE THEORETICAL TREATMENTS AND THE AVERAGE OF GROUPS OF FOUR SUCH PLOTS ARRANGED *Adjacent* TO EACH OTHER

Treatment No.	Yield in pounds					Treatment No.	Yield in pounds				
	Of ultimate unit plots				Average for treatment		Of ultimate unit plots				Average for treatment
1	121	140	141	137	135	26	117	129	152	126	131
2	128	133	138	107	127	27	121	150	136	142	137
3	105	105	124	121	114	28	144	126	103	104	119
4	130	116	136	139	130	29	99	115	110	128	113
5	128	136	133	122	130	30	128	119	119	135	125
6	138	144	146	117	136	31	137	119	110	132	125
7	115	122	108	100	111	32	130	134	134	147	136
8	127	116	139	130	128	33	124	139	146	135	136
9	140	133	100	124	124	34	96	110	109	99	104
10	116	122	118	152	127	35	116	122	137	129	126
11	128	138	129	131	132	36	112	127	132	121	123
12	153	165	155	140	153	37	104	129	148	135	129
13	131	149	120	123	131	38	140	146	119	135	135
14	103	141	140	133	129	39	157	143	103	106	127
15	135	127	148	133	136	40	110	112	113	109	111
16	155	144	155	150	151	41	126	116	115	116	118
17	142	150	136	132	140	42	138	121	119	131	127
18	130	132	131	116	127	43	127	147	137	138	137
19	114	115	138	153	130	44	128	126	87	95	109
20	129	139	143	142	138	45	111	79	98	102	98
21	150	142	140	126	140	46	93	100	93	98	96
22	129	134	114	114	123	47	98	103	97	119	104
23	113	120	140	129	126	48	108	127	119	135	122
24	122	113	108	113	114	49	120	121	114	107	116
25	120	125	138	115	125						

Discarding 3 abnormal plots, there remain 196 plots of practically 8 trees each in the entire field. If 4 of these plots are assigned to each treatment, making a total of 32 trees, in harmony with previous study, it is possible to try 49 treatments in the experiment. Let us assume that each of these theoretical treatments is located on 4 contiguous plots. The average yield for these 4 plots now becomes the average yield for the given treated area. Table 9 shows the results obtained in this field by combining adjacent plots in this way. The extremes of production of the summation plots show a range in average annual yield per tree of from 96 to 153 pounds. During the six-year period the high-yielding group of 4 plots produced, therefore, practically 60 per cent more fruit than the low-yielding group. This error might have been extremely misleading had the plots been under different cultural or fertilizer conditions, and might have frustrated all attempts to draw accurate conclusions as to the effect of the treatments.

TABLE 10

THE AVERAGE ANNUAL YIELDS PER TREE OF THE ULTIMATE UNIT PLOTS OF FORTY-NINE THEORETICAL TREATMENTS AND THE AVERAGES OF GROUPS OF FOUR OF SUCH PLOTS *Scattered at Regular Intervals*

Treatment No.	Yield in pounds: Of ultimate unit plots				Yield in pounds: Average for treatment	Treatment No.	Yield in pounds: Of ultimate unit plots				Yield in pounds: Average for treatment
1	121	149	138	135	136	26	122	138	132	128	130
2	140	120	115	140	129	27	108	153	130	126	129
3	141	123	117	146	132	28	100	128	134	87	138
4	137	103	129	119	122	29	127	139	134	95	124
5	128	141	152	135	139	30	116	143	147	111	129
6	133	140	126	157	139	31	139	142	124	79	121
7	138	133	121	143	134	32	130	150	139	98	129
8	107	135	150	103	124	33	140	142	146	102	133
9	105	127	136	106	119	34	133	140	135	93	125
10	105	148	142	110	126	35	100	126	96	100	106
11	124	133	144	112	128	36	124	129	110	93	114
12	121	155	126	113	129	37	116	134	109	98	114
13	130	144	103	109	122	38	122	114	99	98	108
14	116	155	104	126	125	39	118	114	116	103	113
15	136	150	99	116	125	40	152	113	122	97	121
16	139	142	115	115	128	41	128	120	137	119	126
17	128	150	110	116	126	42	138	140	129	108	129
18	136	136	128	138	135	43	129	129	112	127	124
19	133	132	128	121	129	44	131	122	127	119	125
20	122	130	119	119	123	45	153	113	132	135	133
21	138	132	119	131	130	46	165	108	121	120	129
22	144	131	135	127	134	47	155	113	104	121	123
23	146	116	137	147	137	48	140	120	129	114	126
24	117	114	119	137	122	49	131	125	148	107	128
25	115	115	110	138	120						

EFFECT OF SCATTERING TREATMENT PLOTS

If, on the other hand, 4 repetitions of each of the 49 different theoretical treatments are distributed at regular intervals throughout the field, instead of being located adjacent to each other, we might theoretically expect a reduction of this error. Table 10 shows the results obtained when this is done. This table gives the yields of each of 4 plots chosen in regular numerical rotation along each block and also the average annual yield per tree of the summation plot for each theoretical treatment. According to this arrangement the 49 theoretical treatments show a range in average annual yield per tree of from 106 to 139 pounds. With this distribution, therefore, the high-yielding group of plots has produced 31 per cent more fruit during the six-year period than the low-yielding group of plots.

It is plain from the above calculations that even the scattering of 4 unit plots at regular intervals throughout the field, does not sufficiently reduce the differences between the theoretically treated plots. Conclusions have frequently been drawn, and recommendations have often been made, from field trials conducted in the past when the differences were substantially less than 30 per cent. The studies of many investigators have pointed out this source of error in field trials as being attributable to the varying productivity of the soil. It is clear that some other method of combining the ultimate unit plots, into a more equal summation yield for a given treatment, is necessary. Otherwise only very large differences, of 50 per cent or more, between respective treatments repeated in numerical series as above could be considered significant in the trials which are planned for this experiment.

ARRANGEMENT OF PLOTS ON BASIS OF PRODUCTIVITY

The limitation of the accuracy of chance distribution of a particular treatment, repeated a small number of times has pointed to the advisability of a different arrangement. The tendency which has been indicated to date for either high or low-yielding plots to continue so, has prompted the arrangement of the differential treatments in this field on the basis of their productivity. If the variations in the productivity of different portions of the field under consideration are consistent year after year, or even partially so, as the data which have been obtained seem to indicate, there should be a reduction in the error of the field trials herein proposed by a distribution of the ultimate unit plots in full consideration of the knowledge of the differences which exist.

Means of Determining Reliance to be Placed on Yields Prior to the Start of the Experiment.—The degree of reliance which can be placed upon the apparent productivity of the individual plots, as indicated by the yields of six years, may possibly decrease in the future. This possibility will be subject to further study. As a result of the observations to be made, it may be possible to bring any changes in the degree of reliance of these records to bear upon the comparisons to be made between differently treated plots.

For the purpose of measuring the reliability of the index of relative yield, as here used, 25 of the 196 utilizable plots will continue to be devoted to statistical study bearing on this question. This group of 25 plots will have uniform fertilizer and cultural treatment. These plots have been selected arbitrarily with regard to a presumably satisfactory geographical distribution, and also in such a way that their yields fairly represent the extremes of variation in the field, yet their average yield is equal to that of the entire field. In addition, each particular plot has been selected so that its previous yield is equal to the average yield of a definite area of plots adjacent to it. They will, therefore, serve as indices of the effect of future seasons and growth upon individual plots and upon the local areas about them, as well as upon the field as a whole. In this way they may be reliable guides as to the validity of the use of *a priori* records in planning the field trials herein described.

Method of Distributing Treatment Plots.—After the twenty-five plots just discussed[7] have been distributed throughout the field, there remain 168 plots which may be used for 42 trials of 4 plots each. The treatments have been so distributed that each will be located on a group of 4 ultimate unit plots, the summation yield of which has been approximately equal to the summation yield of the group of plots devoted to each other treatment.

The method which has been used to effect the equalization of the yielding capacity of each group of 4 plots devoted to each treatment is as follows. The observed yields of the individual plots were arranged in order of their descending value. The list was then divided into quartans. The four quartans of plots may be designated as good, medium, low and poor yielding. If each treatment is distributed with one plot in each quartan, the summation yields for all treatments becomes approximately equal. The yields arbitrarily combined in this way are set forth in table 11, stated as the average yearly production per tree for each combination of plots.

[7] In addition to the before-mentioned 25 plots, 3 plots were eliminated for the purpose of using them for demonstration work. Plots F54, L24, and L34 are discarded, as previously noted, because of pocket-gopher injury to the trees.

TABLE 11

The Average Annual Yields Per Tree of the Ultimate Unit Plots of Forty-two Theoretical Treatments and the Average of Groups of Four such Plots Arranged *on the Basis of Yield* and other Factors

Treatment No.	Yield in pounds					Treatment No.	Yield in pounds				
	Of ultimate unit plots				Average for treatment		Of ultimate unit plots				Average for treatment
1	148	126	124	105	126	22	139	130	120	116	126
2	139	129	124	111	126	23	146	138	115	103	126
3	135	133	116	116	125	24	144	133	115	112	126
4	155	130	119	100	126	25	155	122	117	108	126
5	153	135	122	93	126	26	153	128	115	103	125
6	138	133	129	104	126	27	137	126	122	120	126
7	139	128	119	116	126	28	137	132	122	110	125
8	140	126	119	116	125	29	165	146	113	79	126
9	144	133	115	110	126	30	152	136	114	96	125
10	150	128	121	100	125	31	150	129	119	105	126
11	142	137	127	100	127	32	136	135	121	112	126
12	150	121	119	113	126	33	135	128	127	114	126
13	142	141	122	97	126	34	147	136	114	106	126
14	139	134	119	108	125	35	138	135	128	98	125
15	148	146	120	93	127	36	140	135	125	104	126
16	157	132	131	87	127	37	142	128	126	108	126
17	155	132	121	98	127	38	147	129	119	103	125
18	140	131	129	102	126	39	141	132	119	107	125
19	152	138	116	98	126	40	140	138	127	99	126
20	134	131	124	110	125	41	150	130	126	99	126
21	142	140	114	109	126	42	140	136	118	113	127

By this method the grouping of the plots to be used for individual fertilizer treatments has been accomplished in such a way that their average yields per tree prior to the start of the experiments are approximately the same, and within a very narrow range are equal to the average production per tree of the entire field. The table indicates that the average yearly production per tree for the highest-yielding group of plots is 127 pounds, while the average for the lowest-producing group is 125 pounds. By this arrangement[8] the best-yielding group has produced 1.6 per cent more fruit than the lowest yielding. This difference is practically negligible in trials of this sort.

This arrangement was adopted in order that the greatest accuracy of comparison might be attained by the customary statistical methods.

8 In choosing the plots from each class to be used for a given treatment a particular effort was made, at the same time, to so locate them that the various repetitions of each treatment would be scattered satisfactorily from the point of view of variations in soil type, visual comparisons of contrasting treatments, ease of culture, and adequate geographical distribution.

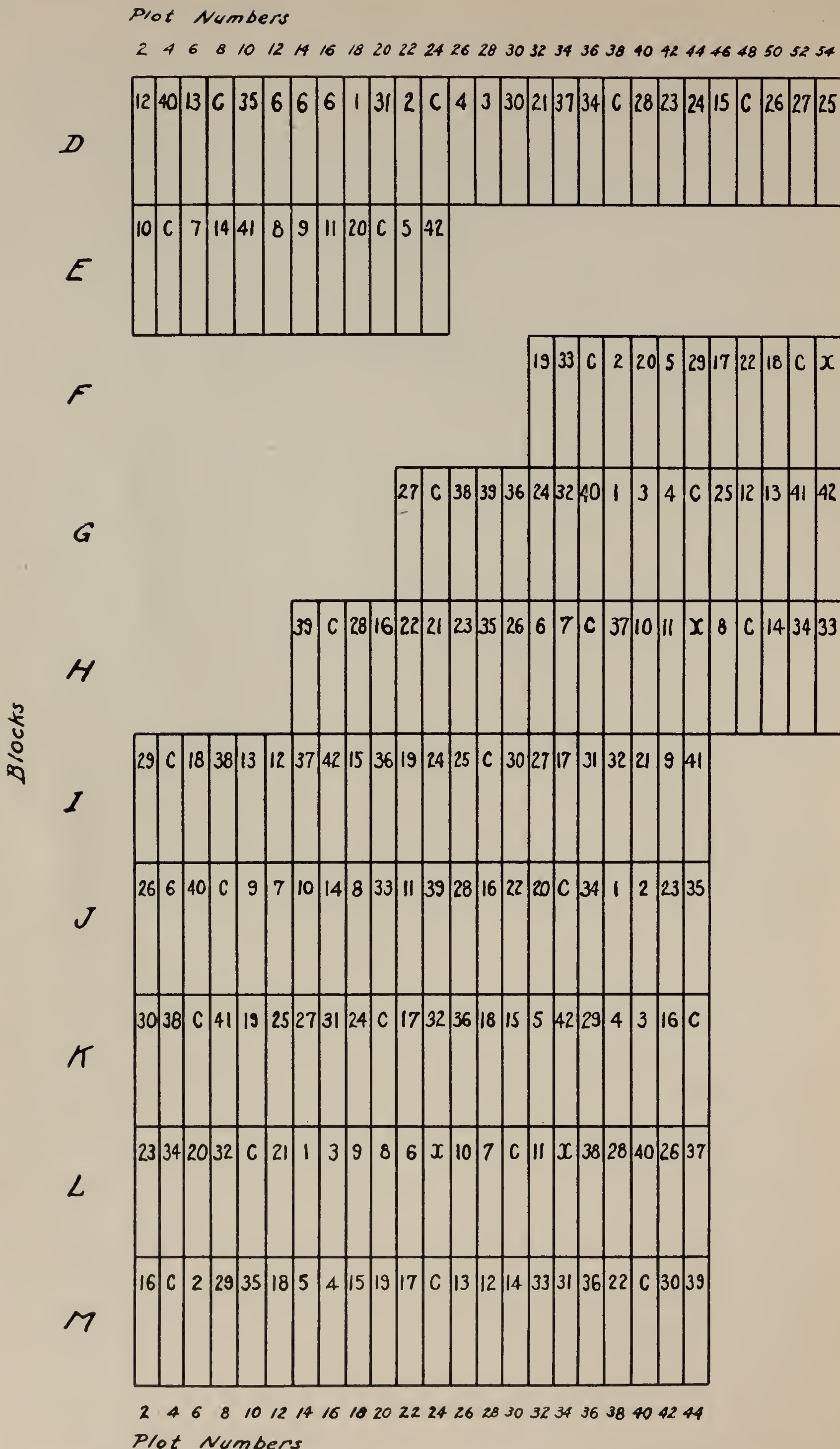

Fig. 13.—Diagram of experimental field showing location of the respective treatments by number.

In case differences in relative production of various plots which have been observed to date do not prove to be maintained in the future, it may still be feasible to draw conclusions as to the effect of the treatments by taking into account the trend of changes in relative productivity in various sections of the field as indicated by the 25 'continuity' plots, and by the use of standardized methods of measuring the significance of differences between groups of plots.

The location in the field of each treatment is shown in figure 13. In this illustration the various plots are designated, first, by the letter of the block in which they occur, and, second by the number of the plot in the particular block. The letters designating the blocks are shown on the left margin, and plot numbers in each block are shown along the top and bottom margins of the diagram. The treatments assigned to each plot are indicated by numerals placed in each respective plot space. The treatment which each plot receives may be found by reference to table 12, which also contains a list of all plots receiving a given treatment.

TABLE 12

LIST AND LOCATION OF TREATMENTS WITH AMOUNTS OF CERTAIN FERTILIZER INGREDIENTS APPLIED DURING THE EARLY YEARS OF THE EXPERIMENT

(Four plots per treatment unless otherwise stated)

Materials and treatment	Pounds of nitrogen (N), phosphoric acid (P_2O_5), potash (K_2O), applied per tree per year from each material	Location in field			
"C" (25 plots)					
Ammonium nitrate	0.33 N	D 8	F36	H48	K20
Blood	0.17 N	D24	F52	I 4	K44
Manure	0.50 N	D38	G24	I 28	L10
Cover crop	....	D48	G44	J 8	L30
		E 4	H16	J34	M 4
		E20	H36	K 6	M24
					M40
1. No treatment	....	D18	G38	J38	L14
No cover crop	....				
2. Ammonium nitrate	1.0 N	D22	F38	J40	M 6
No cover crop	....				
3. Ammonium nitrate	1.0 N	D28	G40	K40	L16
Triple superphosphate	1.0 P_2O_5				
No cover crop	....				
4. Ammonium nitrate	1.0 N	D26	G42	K38	M16
Triple superphosphate	1.0 P_2O_5				
Sulphate potash	1.0 K_2O				
No cover crop	....				
5. Ammonium nitrate	1.0 N	E22	F42	K32	M14
Sulphate of potash	1.0 K_2O				
No cover crop	....				
6. Cover crop alone (6 plots)	....	D12	H32	J 4	L22
7. Ammonium nitrate	1.0 N	E 6	H34	J12	L28
Cover crop	....				

TABLE 12—(*Continued*)

Materials and treatment	Pounds of nitrogen (N), phosphoric acid (P_2O_5), potash (K_2O), applied per tree per year from each material	Location in field			
8. Ammonium nitrate	1.0 N	E12	H46	J18	L20
Triple superphosphate	1.0 P_2O_5				
Cover crop	....				
9. Ammonium nitrate	1.0 N	E14	I 42	J10	L18
Triple superphosphate	1.0 P_2O_5				
Sulphate of potash	1.0 K_2O				
Cover crop	....				
10. Ammonium nitrate	1.0 N	E 2	H40	J14	L26
Triple superphosphate	1.0 P_2O_5				
Muriate of potash	1.0 K_2O				
Cover crop	....				
11. Ammonium nitrate	1.0 N	E16	H42	J22	L32
Sulphate of potash	1.0 K_2O				
Cover crop	....				
12. Ammonium sulfate	0.33 N	D 2	G48	I 12	M28
Nitrate of soda	0.33 N				
Blood	0.33 N				
Cover crop	....				
13. Ammonium sulfate	0.33 N	D 6	G50	I 10	M26
Nitrate of soda	0.33 N				
Blood	0.33 N				
Phosphate	1.25 P_2O_5				
Sulphate of potash	0.66 K_2O				
Cover crop	....				
14. Ammonium nitrate	0.33 N	E 8	H50	J16	M30
Blood	0.17 N				
Manure	0.50 N				
Phosphate	1.0 P_2O_5				
Muriate of potash	1.0 K_2O				
Cover crop	....				
15. Ammonium sulfate	1.0 N	D46	I 18	K30	M18
Cover crop	....				
16. Ammonium sulfate	1.0 N	H20	J28	K42	M 2
Limestone	....				
Cover crop	....				
17. Blood	1.0 N	F46	I 34	K22	M22
Cover crop	....				
18. Urea	1.0 N	F50	I 6	K28	M12
Cover crop	....				
19. Ammonium nitrate	0.67 N	F32	I 22	K10	M20
Blood	0.33 N				
Cover crop	....				
20. Nitrate of lime	1.0 N	E18	F40	J32	L 6
No cover crop	....				
21. Nitrate of lime in February	1.0 N	D32	H24	I 40	L12
Cover crop	....				
22. Nitrate of lime in June	1.0 N	F48	H22	J30	M38
Cover crop	....				
23. Nitrate of lime in October	1.0 N	D42	H26	J42	L 2
Cover crop	....				
24. Nitrate of lime in three applications	1.0 N	D44	G32	I 24	K18
Cover crop	....				
25. Nitrate of lime	0.50 N	D54	G46	I 26	K12
Nitrate of soda	0.50 N				
Cover crop	....				
26. Nitrate of soda	1.0 N	D50	H30	J 2	L42
No cover crop	....				

TABLE 12—(*Concluded*)

Materials and treatment	Pounds of nitrogen (N), phosphoric acid (P_2O_5), potash (K_2O), applied per tree per year from each material	Location in field			
27. Nitrate of soda	1.0 N	D52	G22	I 32	K14
Cover crop	....				
28. Nitrate of soda	1.0 N	D40	H18	J26	L38
Gypsum	....				
Cover crop	....				
29. Nitrate of soda	0.50 N	F44	I 2	K36	M 8
Manure	0.50 N				
Cover crop	....				
30. Manure broadcast in fall	1.0 N	D30	I 30	K 2	M42
No cover crop	....				
31. Manure broadcast in fall	1.0 N	D20	I 36	K16	M34
Cover crop	....				
32. Manure broadcast in spring	1.0 N	G34	I 38	K24	L 8
Cover crop	....				
33. Manure in furrows in fall	1.0 N	F34	H54	J20	M32
Cover crop	....				
34. Ammonium nitrate	0.33 N	D36	H52	J36	L 4
Blood	0.17 N				
Manure	0.50 N				
Gypsum	....				
Cover crop	....				
35. Ammonium nitrate	0.33 N	D10	H28	J44	M10
Blood	0.17 N				
Manure	0.50 N				
Limestone	....				
Cover crop	....				
36. Alfalfa hay on nitrogen basis	0.50 N	G30	I 20	K26	M36
Ammonium nitrate	0.33 N				
Blood	0.17 N				
Cover crop	....				
37. Bean straw on nitrogen basis	0.50 N	D34	H38	I 14	L44
Ammonium nitrate	0.33 N				
Blood	0 17 N				
Cover crop	....				
38. Wheat straw on nitrogen basis	0.50 N	G26	I 8	K 4	L36
Ammonium nitrate	0.33 N				
Blood	0.17 N				
Cover crop	....				
39. Wheat straw on organic matter basis	0.13* N	G28	H14	J24	M44
Ammonium nitrate	0.58 N				
Blood	0.29 N				
Cover crop	....				
40. Amount halved	....	D 4	G36	J 6	L40
Ammonium nitrate	0.17 N				
Blood	0.08 N				
Manure	0.25 N				
Cover crop	....				
41. Amount doubled	....	E10	G52	I 44	K 8
Ammonium nitrate	0.67 N				
Blood	0.33 N				
Manure	1.0 N				
Cover crop	....				
42. Amount trebled	....	E24	G54	I 16	K34
Ammonium nitrate	1.00 N				
Blood	0.50 N				
Manure	1.50 N				
Cover crop	....				

* Based on analysis of material applied spring of 1927.

DIFFERENTIAL FERTILIZER AND CULTURAL TREATMENTS

The gradual increase in the knowledge of the culture and nutrition of citrus fruits has raised a large number of questions for solution which may properly be included among the trials under consideration. However, the purposes of these trials are not confined to the determination of the effect of specific treatments on the production of oranges alone. It is expected that the effect of many of the fertilizer treatments may cause such ultimate differences in the soil conditions, that valuable material will be produced for future laboratory studies upon the fundamental processes which may be involved. The effect of some of the treatments may not be apparent during the early progress of the trials, but the continued application of these materials may have a gradual effect upon both the trees and the soil[9] which may be cumulative with the passing of time.

The great diversity and the seeming importance of the problems which have been raised have prompted an effort to secure suggestions from many sources. On August 28, 1926, a general meeting was called for this purpose at the Citrus Experiment Station by the Director. Citrus growers, members of the Staff of the College of Agriculture and those interested in the sale of fertilizer materials, have all contributed to the plans finally adopted. Frequent conferences have been held informally with these persons.

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[9] In order that adequate material may be supplied for laboratory studies upon the source of changes which may be produced in the soil after various treatments, the soil of this orchard has been thoroughly sampled, once during the winter of 1918–19, and again at the time the differential treatments commenced in February, 1927. These samples are now in storage. It is planned that soil samples will be taken at periodic intervals throughout the duration of the experiments for use in laboratory studies. Although the materials which will be applied will be as pure as it is practicable to purchase commercially, it is also planned that samples of them will be taken for future study. Hence, it may be possible to determine whether or not the effects of the treatment are actually due to the material being consciously tested, or to the effects of impurities in it. The arrangement of the experimental field and the nature of the trials which are described are the results of the combined efforts of a large number of people. In connection with the planning of the treatments suggestions have been sought from many sources. The advice of many members of the staff of the Citrus Experiment Station has been of great influence in determining the nature of the trials to be made. Among these men are H. J. Webber, A. R. C. Haas, W. P. Kelley, W. R. Schoonover, J. Gordon Surr, and R. S. Vaile. The successful supervision of the field work, which is essential to an experiment of this kind, has been due at various times to the efforts of W. M. Mertz, J. A. Prizer, and Charles Wilson.

The trials indicated in table 12 have been selected as incorporating the most essential ideas involved in the suggestions which have been made. The elimination of many trials which possibly would have contributed much valuable information was necessitated by the physical limitations of the experimental field.

As heretofore stated, each of the 42 treatments is repeated four times. These repetitions are distributed on the basis which has been discussed in the previous section of this paper. The location of each in the field is shown in table 12. In general the amounts of the elements or materials applied are in harmony with conservative commercial practice. During the early years of the trials it is expected that, unless otherwise stated, one pound of actual nitrogen (N), phosphoric acid (P_2O_5), and potash (K_2O), respectively, will be applied per tree each year, in each instance where these materials are used. This general rule is to be followed regardless of the material by which they are supplied. Gypsum and limestone are to be used at the rate of one ton per acre per year, the gypsum to be supplied annually and the limestone every four years. The concentrated fertilizers are to be applied in the early spring unless otherwise stated. The bulky organic materials are to be applied in the late summer or early fall with the exception of one treatment.

Any discussion or grouping of the treatments on the basis of their experimental purposes involves some duplication and perhaps some confusion. Many comparisons may be made between a single trial and several other trials, not all of which can be placed in a simple outline of comparison. In indicating the general scope and some of the chief divisions of the experiments, however, it may be well to call attention to the treatments which most obviously fall under each division.

The more general groups of treatments to be employed follow. Experimental trials are referred to by number, the exact treatment of which may be obtained from table 12.

A. As heretofore noted, 25 plots, designated as '*C*' plots, have been distributed throughout the field to indicate the degree of the *continuity of differences* of normal yield of various parts of the field. These plots will serve as indices of relative fertility and will be an aid in the interpretation of all results. The standard amount of one pound of nitrogen per tree is to be applied annually during the first few years of the experiment. One-half the nitrogen is to be in the form of concentrated materials applied in the spring, and one-half as bulky organic material applied in the fall. The concentrated mate-

rials will consist of ammonium nitrate, which will supply ⅓ pound of nitrogen, and dried blood, which will supply ⅙ pound of nitrogen. The bulky organic material will be dairy manure, and will supply one-half the total nitrogen applied. Winter cover crops will also be grown on all *C* plots.

B. A series of trials have been installed to determine the effects of nitrogen, phosphoric acid, and potash, with and without a cover crop. This group of treatments may be subdivided as follows:

I. Ten treatments involve essentially the use of ammonium nitrate (N), triple superphosphate (P), sulphate of potash (K), and cover crop. The materials are applied in standard quantities alone and in the following combinations:

Clean culture No.				Cover crop No.			
1.	—	—	—	6.	—	—	—
2.	N	—	—	7.	N	—	—
3.	N	P	—	8.	N	P	—
4.	N	P	K	9.	N	P	K
5.	N	—	K	11.	N	—	K

II. One treatment (No. 10) substitutes muriate of potash in treatment 9 above to determine the possible effect of accumulations of chlorin as compared with the sulfate radicle in the presence of nitrogen and phosphoric acid.

III. Two trials (Nos. 12 and 13) were inaugurated to determine the value of phosphoric acid and potash in the presence of several nitrogen-carrying fertilizers combined. The standard amount of actual nitrogen, one pound per tree, has been used, but the approximate proportions of the materials used to supply it, and also the amounts of phosphoric acid and potash used, have been determined by averaging the four most popular so-called 'complete commercial fertilizers' used at the present in citrus orchards. This average gave fertilizers of the order of 7.5 per cent N, 9.25 per cent P_2O_5, 4.75 per cent K_2O. When all fillers are eliminated this becomes 9.7 :11.9 :6.15, which is the formula employed. The materials used are ammonium sulfate, nitrate of soda, and blood (each supplying one-third of the total nitrogen), triple-superphosphate and sulfate of potash. The 'complete fertilizer' has been commercially mixed. These two trials may logically be compared directly with several others in this series, as a study of table 12 will show.

IV. One trial (No. 14) deals with the value of additions of phosphoric acid and potash in the presence of manure when the latter is

supplied in such an amount that it provides one-half the total quantity of nitrogen applied.

V. The necessity of nitrogenous fertilization in the culture of citrus fruits in California has stimulated the adoption of an extensive series of trials of nitrogen-carrying materials (Nos. 2, 7, 15, 16, 17, 18, 19, 20, 21, 26, 27, 28, 29, 30, 31). These have been chosen in an effort to determine the efficiency of various substances supplying equal amounts of total nitrogen. The results of continued applications of various chemical constituents associated with the carriers, and the interrelations of several of these constituents will also be the subject of study. The effect of the so-called 'soil amendments' may also be considered in this section, since they contain chemical constituents which may react with the fertilizer material. Clean culture and cover cropping will be employed in special instances in an attempt to determine the effect of organic matter on the soil reactions to various fertilizer materials as well as on tree growth.

VI. The effect of supplying nitrogenous material at various seasons will be studied (Nos. 21, 22, 23, 24, 31, 32). These materials will consist of nitrate of lime and dairy manure, respectively, each to supply the standard amount of nitrogen. The nitrate of lime will provide nitrogen in an available form and will give some information as to the time at which citrus trees require this material for best response. The manure will serve for the study of the reaction of the tree and soil to organic and slowly available nitrogenous materials when applied at different seasons.

VII. The method of applying bulky organic materials (Nos. 31, 32, 33) is the subject of a trial comparing the application of dairy manure by means of broadcasting and in furrows.

VIII. Four trials (Nos. 16, 28, 34, and 35), are being made to determine the effects of soil amendments under various conditions of culture.

IX. The effect of the addition of various bulky organic materials is to be studied in an effort to determine the specific effect of such materials, the desirable amount of organic matter to apply, and also the value of materials low in nitrogen. In certain trials the organic materials will be applied in such a quantity that they will supply half the total nitrogen (Nos. 36, 37, 38, and *C*). The amount of organic matter will therefore vary in quantity with the materials used. In another trial (No. 39) the bulky materials will be applied in such amounts that the organic matter to be added in the form of

wheat straw will be equal to that contained in dairy manure when the latter material supplies half the total nitrogen. In all cases the total nitrogen applied will be made up to the standard amounts with ammonium nitrate and dried blood.

X. The effect upon trees and soil of supplying various total amounts of nitrogen will be investigated in certain trials (Nos. 40, 41, 42, and *C*). These experiments will serve as a guide in determining the standard amount of this element to be applied in the future years on this experimental field. They may also give some information as to the most economical use of nitrogenous fertilizers on Ramona loam and on similar soil types. The nitrogen in this series of trials is to be derived from concentrated and bulky material as follows: two-sixths of the total amount to be supplied by ammonium nitrate, one-sixth by dried blood, and three-sixths by dairy manure.

APPENDIX

COST OF DEVELOPING AND MAINTAINING THE EXPERIMENTAL GROVE DURING THE FIRST TEN-YEAR PERIOD

A record has been kept of the expenses incurred in the development of the experimental orchard. Several of the ordinary items of expense which must be met by the commercial grower have naturally not been among the necessary charges met by a state institution. Among such charges are taxes, interest on investment and, in this particular instance, the usual expense of water rights, which may normally be charged against such an enterprise. The actual cost of the development as experienced can not, therefore, be used as an absolute criterion of the expense which may be anticipated in connection with the establishment of a commercial orchard. It may, however, be interesting to present the record of the actual cost of development plus the ordinary average charges which would have been made against such a property were it owned and financed by a private commercial organization.

The actual ten-year expenditure for development by the Experiment Station, including original capital investment less the assumed charge of $200 an acre for water, plus material and labor equals $1,508.26 an acre. During the same period the sale of the bean intercrops plus the sale of the fruit totaled $1,653.13. The orchard has thus repaid all capital expenditure and costs of operation, and shows a balance of $144.87 an acre to the Experiment Station at the end of the first ten-year period.

TABLE 13

SUMMARY OF ACCUMULATED COST PER ACRE OF DEVELOPING ORANGE AND GRAPEFRUIT ORCHARD

(Includes charges for supervision, taxes, depreciation and interest. Sales are credited.)

	Material and labor	Supervision and miscellaneous labor	Taxes*	Interest*† at 6%	Total charges	Sales total net returns	Net debit	Net credit	Total accumulated investment
Original capital investment......	$676.10‡								$ 676.10
July 1, 1917, to June 30, 1918....	45.63	$37.46	$ 5.00	$40.57	$128.66	$ 46.19§	$ 82.47		758.57
July 1, 1918, to June 30, 1919....	51.75	37.46	5.00	45.51	139.72	25.16§	114.56		873.13
July 1, 1919, to June 30, 1920...	69.23	37.46	5.00	52.39	164.08	54.08§	110.00		983.13
July 1, 1920, to Dec. 31, 1920....	22.54	18.73	2.50	29.49	73.26	46.23§	27.03		1010.16
Jan. 1, 1921, to Dec. 31, 1921....	99.30‖	37.46	7.00	60.61	204.37	56.48¶	147.89		1158.05
Jan. 1, 1922, to Dec. 31, 1922....	86.79	37.46	7.00	69.48	200.73	184.77¶	15.96		1174.01
Jan. 1, 1923, to Dec. 31, 1923....	291.60+	37.46	11.00	70.44	410.50	55.57¶	354.93		1528.94
Jan. 1, 1924, to Dec. 31, 1924....	156.44‖	37.46	11.00	91.74	296.64×	215.15¶	81.49		1610.43
Jan. 1, 1925, to Dec. 31, 1925....	94.72	37.46	11.00	96.63	239.81×	495.91¶		$256.10	1354.33
Jan. 1, 1926, to Dec. 31, 1926....	114.16‖	37.46	11.00	81.26	243.88×	473.59¶		229.71	1124.62

* Charges made but not actually paid.

† Interest is charged on total accumulated investment existing at end of previous fiscal period, but not on operating charges or surplus of the current period.

‡ Includes charges as follows

Cost of land	$300.00
Average cost of water	200.00
Pipe lines, installed	91.40
Preparing land	10.00
Digging holes	2.70
Balling trees	4.50
Trees, 90 at 75 cents	67.50
Total	$676.10

§ Receipts from sale of beans.

‖ Includes charges for fumigation.

¶ Receipts from sale of fruit.

+ Includes $202.64 for orchard heating equipment

× Includes depreciation on heating equipment at 5 per cent per annum ($10.13).

The figures presented in table 13, on the other hand, show the normal costs of developing the grove if such charges as taxes, water rights, and interest on capital invested were charged against the undertaking. The figures given herein may, therefore, be used by the reader as a basis of comparison and as an aid in estimating the cost of establishing a commercial grove. It will also be our endeavor to show where the charges made and the receipts obtained may be in any way uncommon, in order that the records may not be misleading if taken as a reasonable estimate of such costs. The actual capital investment per acre for land, a theoretical charge for water rights,[10] the cost of installation of pipe lines, and that of planting of trees are indicated in a footnote to table 13.

Although pipe lines are located at 200-foot intervals and the cost of this item is greater than in the usual planting, the costs of other items are rather low. The price of the land, $300, is low compared with the present ruling prices being paid in this and other comparable orange-growing districts. The cost of trees is somewhat below the average, the trees were all grown at the Experiment Station.

The frost-protection equipment purchased in 1923 and charged in table 13, consists partly of fifty 9-gallon heaters per acre, one 500-gallon tank wagon to each 8 acres, sufficient oil storage and oil to refill all of the heaters four times, a frost-alarm system, filling buckets, and torches. The initial charge for this equipment was $202.64 per acre. Depreciation has been charged on this equipment at the rate of 5 per cent per annum.

No other investment charge for equipment has been made for this particular grove. The tools, teams, and tractor used on all projects of the Experiment Station have been employed, and flat charges have been made against this acreage according to the services rendered.

The cultivation work has been done mainly with a tractor. The prevailing rate of $2.50 an hour has been charged for all tractor work. The rate charged for team work has been $0.75 an hour for team and man. Other labor has been charged at current rates.

The charge for irrigation water has approximated very closely the average which would have been experienced had actual stock in the Gage Canal Company been held by this property. This average is $10.65 an acre annually for the average amount used. Nearly all the

[10] A theoretical charge of $200 per acre for water rights is included. The grove is in the midst of a large acreage of citrus served by the Gage Canal Co. The average market value per acre of stock of this system commonly used is therefore used as the theoretical charge. (See Blaney, Harry F. Cost of water to irrigators in California. California State Dept. Public Works, Div. Eng. and Irrig. Bul. 8:1–66. 1925.)

fertilizer which has been used has been the legumes grown on the land, excepting that one-half ton of alfalfa straw per acre was purchased in 1924, and spread in the irrigation furrows to retard the movement of irrigation water and facilitate its penetration. Certain cultural costs are higher than would occur in commercial practice. Extra care has been taken to have all of the operations done as uniformly and exactly as possible over the entire planting. This is particularly true of irrigation. Certain charges included under supervision are for record keeping. These charges are for weighing of beans and of fruit, measuring the top volume and trunk circumference of the trees, etc.

This property has been favored with comparative freedom from serious tree diseases. Insect pests have been readily kept under control. Fumigation has been necessary only three times, in 1921, 1924, and 1926.

The grove has returned some revenue every year since and including the year it was planted. The returns the first four years were from the sale of Black-eye beans, grown on the land as an intercrop. The total receipts for the four years from the sale of beans were $171.66 an acre. This very favorable return was influenced by the fact that the beans were grown during and immediately following the period of the World War when especially high prices were received for this commodity. In spite of the return from the sale of beans during the first four years, the cultural maintenance charges were such that the capital investment had increased to $1,010.16 an acre at the time when the trees came into production.

The total amount received from the sale of fruit for all years was $1,481.47 an acre, and represents the value of six crops of fruit from the grove, from its fourth year to and including its ninth year. All of the fruit has been sold by the California Fruit Growers Exchange. The returns over the six-year period include the usual fluctuations in prices.

Table 13 indicates the capital investment under the heading ''Total accumulated investment'' at the close of each fiscal year from the time of planting until June 30, 1920, and for each calendar year from that time until December 31, 1926. It may be observed that the first year in which an actual profit occurred was 1925, at which time the orchard was eight years old. The capital investment was decreased both that and the following year. At the close of the period under discussion the total investment amounted to $1,124.62, which is the net cost of the grove per acre to December 31, 1926. An evaluation of the grove with its improvements by a disinterested professional

appraiser was made at that time. A conservative estimate of $1,500 per acre was arrived at. It was stated that this amount should be realized if the property were disposed of at a forced sale. The difference between this figure and the total accumulated cost represents the theoretical profit from the undertaking from a commercial point of view. This figure amounts to $375.38 per acre, or $18,037.01 for the entire tract of 48.05 acres.

TABLE 14

Net Returns* for Varieties per Pound, 1921–1926, Inclusive

Variety or kind	1921	1922	1923	1924	1925	1926	Average
Navels	$0.02125	$0.04810	$0.02125	$0.01092	$0.04212	$0.03228	$0.02932
Valencias	.02162	.03349	.01311	.02403	.05962	.03423	.03107
Grapefruit	.01981	.04261	—.00649†	.01653	.03498	.03166	.02318

* Net to grower.

† Packing, selling, and transportation charges exceeded the gross returns by this amount.

The net prices received per pound for each variety of citrus—Valencia and Navel oranges and Marsh Seedless grapefruit—each year, are noted in table 14. In general they are typical of average prices paid during these years, and are influenced by the usual factors affecting supply and demand. The value per pound of all marketable fruit was increased in 1922 by the occurrence of a freeze which cut down the total amount of fruit shipped. This freeze did not, however, affect the accuracy of the yield records of Navel oranges. Heaters were installed in 1923, and no further loss has been experienced from this source. Although the average price has been satisfactory, the returns per pound from the sale of grapefruit have been more variable than from the sale of the two varieties of oranges.

As a basis of comparison of the returns from the three varieties of fruit, their production has been calculated as if they were in a solid planting. The average yield of a solid acre of each variety is noted in table 15 for each of the six years under discussion, as well as the total for this period. The heavier production of grapefruit is notable. The total production of Navels and Valencias is about equal, but it is apparent that certain years have been more favorable for the production of one variety than for the other in this particular orchard under conditions of uniform care. In 1922, for example, the damage from frost was not so severe in the cases of the Valencias and the grapefruit as in the case of the Navels. The yield of Navels was markedly higher than that of Valencias in 1925 for some reason which has not been ascertained.

The total gross return from all three varieties has been calculated on the acre basis and appears in table 16. Over the six-year period Valencias and grapefruit have netted about an equal amount and have been slightly more profitable than Navels. The greater return from grapefruit during 1921 and 1922 is a noticeable feature of this table, although an actual loss occurred with this crop in 1923.

TABLE 15

Yield of Varieties on an Acre Basis,* 1921–1926, Inclusive
(Pounds)

Variety or kind	1921	1922	1923	1924	1925	1926	Total
Navels	1,945†	2,669‡	6,168†	11,924†	13,085†	10,678†	46,469
Valencias	1,948	5,330	5,855	10,649	8,227	15,999	48,008
Grapefruit	4,535	6,125	9,160	16,881	12,377	17,606	66,684

* Based on an area of 18.29 acres of Navels, 14.99 acres of Valencias, and 14.77 acres of grapefruit; total area, 48.05 acres.

† Navel yields in this table are somewhat lower than those in table 6, the latter includes windfalls, whereas this table records only fruit which went to packing house.

‡ This is only 37 per cent of total production, remainder not sold on account of frost injury.

TABLE 16

Gross Returns* for each Variety per Solid Acre, 1921–1926, Inclusive

Variety or kind	1921	1922	1923	1924	1925	1926	Total
Navels	$41.33	$128.37	$131.07	$130.21	$551.14	$344.69	$1,326.81
Valencias	42.11	178.50	76.76	255.90	490.49	547.54	1,591.30
Grapefruit	89.82	260.98	—59.45	279.04	432.95	557.40	1,560.74

* Charges for picking and hauling have been deducted

The reader should not use tables 13, 15, and 16 as an indication of the returns which may be reasonably expected from a commercial grove without being fully aware that the average prices set forth in table 14 from 1921 to 1926, inclusive, are considerably above the ten-year average of 1912–22. Furthermore the average price received from the sale of oranges for the years 1925 and 1926, 3.7 cents a pound for Navels and 4.7 cents a pound for Valencias, is approximately double the average return for the ten-year period 1912–22.[11] It was during these two years of high prices that two out of the three really commercial yields were obtained from this orchard. The total returns have, therefore, been considerably higher than can be expected on the average from similar orchards.

[11] Vaile, R. S. A survey of orchard practices in the citrus industry of southern California. California Agr. Exp. Sta. Bul. 374:1–40. 1924.

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